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CABLES AND FIRE HAZARDS

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16. Abstract Besides describing the experiments conducted to develop a nonflammable cable, this article discusses several considerations regarding other hazards which might result from cable fires, particularly the toxicity and opacity of the fumes emitted by the burning cable... In addition, this article examines the effects of using the Oxygen Index as a gauge of quality control during manufacture.			
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CABLES AND FIRE HAZARDS

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INTRODUCTION

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Today there is a growing knowledge of the hazards inherent in electrical cables which might act as a means of propagating fires caused by circumstances which originally do not depend on the cables themselves. Many cable users now accept the idea that, under certain conditions, cables may constitute a fire hazard, and they are searching for ways to reduce this hazard. Several solutions regarding various aspects of this problem have already been proposed, for example the use of nonflammable cable, and several questions have been raised regarding other aspects, such as generation of hydrochloric acid and corrosion, particularly in connection with the new types of nonflammable cables. This indicates a growing interest in this subject and the desire to study the behavior of what could become a new generation of cables. At the same time, it is important to emphasize that modification of cable design is only one part of the program necessary to obtain safer plants. The technical personnel responsible for the design and installation of these plants must also make a contribution.

This article contains several preliminary considerations regarding problems which have always existed but which, until recently, have rarely been discussed in depth.

*Numbers in the margin indicate pagination in the foreign text.

STANDARD TYPES OF CABLE

It is useful to consider the types of cable currently in use which might be modified to reduce the fire-spreading hazards. The following list summarizes cables typically used in Italy and England.

Small Installations (Low Capacity)

Cables insulated with PVC or cables insulated with PVC and underclad with PVC, generally not reinforced, or sometimes reinforced with iron wires or aluminum strips.

Large Industrial Installations (High Capacity)

Cables insulated with PVC or EPR underclad with PVC, not reinforced or reinforced with iron wires or aluminum strips.

Cables insulated with impregnated paper, lead-coated and underclad with PVC, not reinforced or reinforced with iron wires and underclad with PVC.

Stations

Cables insulated with PVC and underclad with PVC, reinforced with aluminum strips. Cables insulated with polythene underclad with PVC and reinforced with iron wires. Cables reinforced with reticulated polythene or EPR underclad with PVC, not reinforced or reinforced with iron wires or aluminum strips. Cables insulated with impregnated paper, lead-coated and underclad with PVC, not reinforced or reinforced with iron wires.

Underground Distribution

Cables insulated with impregnated paper, lead-coated and armored. Cables insulated in reticulated polythene underclad with PVC.

Connections to houses are generally in PVC, EPR or reticulated polythene underclad with PVC.

All the cables described above are inflammatory under determined conditions. It is nevertheless possible to design cables whose burning risks are considerably decreased, and in some cases are rendered negligible. For reasons connected with installation and electrical service, it is desirable to continue to use organic materials (PVC, EPR, Butyl, etc.) for the cable insulation and sheath, whether for low or high capacity. This can be obtained by exploiting the properties of materials containing chlorine by using special additives, causing them to become nonflammable. Of the these materials, PVC provides /362 the most economical solution and, in addition has the advantage of being a material with well known characteristics.

ANTI-FLAME PROPAGATION TEST

The well-known CESI test has been adopted in Italy. The cables are arranged in an installation such as in Fig. 1. Recent modifications include the addition of equipment to purify the gases, thereby reducing the air pollution caused by combustion of organic materials. Arrangement of the cables is shown in Fig. 2. The reinforced concrete structure has an internal dimension (in plan) of approximately 2.5 x 2.5 m and is approximately 5.4 m high. It is divided into two chambers, upper and lower, separated by a slab with an opening to allow the passage of the cables, simulating a passage from one room to another. The cables, each approximately 5.4 m, are secured to a

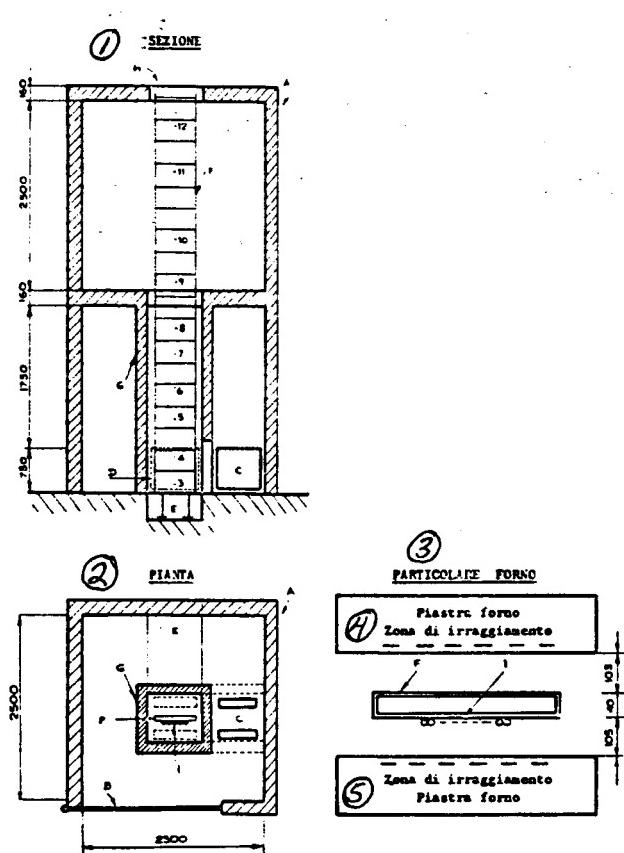


Fig. 1. Sketch of the Test Chamber

A - Two-compartment cabin of reinforced concrete; B - Access door; C - Furnace in extraction position; D - Furnace in insertion position; E - Intake passage; F - Cable support frame; G - Chimney; H - Opening for fume exhaust; I - Test cables.

Thermocouple positions; heights from ground level: 1 to 2 in the furnace; 3 to 200 mm; 4 to 630 mm; 5 to 1100 mm; 6 to 1530 mm; 7 to 1960 mm; 8 to 2390 mm; 9 to 2670 mm; 10 to 3370 mm; 11 to 4220 mm; 12 to 4670 mm.

Key: 1 - Section; 2 - Plan; 3 - Particular furnace; 4 - Furnace plate, Radiation zone; 5 - Radiation zone, Furnace plate.

metal ladder to form two equal bundles on either side of it, approximately 40 mm apart. The number of cables is calculated so that the total weight of organic material is of a prescribed value, for example, 5 or 10 kg/m.

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Fig. 2

At the bottom of the lower chamber is the electric furnace, consisting of two 700-mm-high heating plates situated facing the bundle of cables at a distance of 70 mm.

The furnace is pre-heated in one compartment, on the side where the cables are located, to a temperature of approximately 800°C, which is then transferred onto the cables in the test position by means of appropriate guides. The gases which develop are then ignited with gas burners, which are removed after 15 minutes.

Two tests are prescribed:

- 1) a qualifying test based on a weight of 10 kg per meter of organic material and a flame-propagation limit of 3.5 m, for the purpose of controlling the cable design and of supplying a safety margin for minute discrepancies in size and construction, with relation to:

- 2) an acceptance test based on a weight of 5 kg per meter of organic material and a flame-propagation limit of 1.5 m, which every building lot must satisfy.

TEST RESULTS

Numerous tests conducted have revealed that obtaining a satisfactory test result on a small cable guarantees a positive test result on larger cables of similar construction.

Nevertheless, Table 1 shows the test results of various cables of different sizes which were studied specifically with regard to non-incendiary qualities.

TABLE 1

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Type of Cable	Size mm ²	Weight of Organic Material kg/m	Flame Spreading Limit m
Insulated with PVC, underclad with PVC, reinforced with iron wires, underclad with PVC	2 x 2.5	10.0	0.7
Insulated with PVC, PVC fillers and PVC sheath	3 x 1.5	15.0	0.8
Insulated with EPR, screened, reinforced with iron strips, PVC sheath	3 x 95	10.3	0.35
Insulated with EPR, screened, PVC sheath, reinforced with aluminum wires, PVC sheath	1 x 200	10.8	1.45

COMMENTS ON THE TEST RESULTS

The CESI test was developed in Italy following a serious fire in the La Spezia station, where flame spread along cables was the predominant cause of the destruction of the control panel and the electronic computer. The test reproduces the typical method of cable installation in a thermal station where there are thick cable bundles and vertical passages from one level to the other. This test, which deals exclusively with the problem of flame propagation, has determined those conditions which cause rapid propagation of flames (about 10 meters in the first minute). The test studies the construction of those cables whose flammable properties are negligible, while showing that cables of a conventional construction may represent a fire hazard.

Several useful observations made during the research are briefly outlined below:

- 1) Influence of the quantity of organic material contained in the cable bundle on the rate of flame propagation. The distance of propagation increases with the quantity of material.
- 2) Influence of the size of an individual cable in cable bundles having the same organic material content. Bundles containing many small size cables cause flames to spread more rapidly than bundles containing fewer cables of larger dimensions.
- 3) Influence of the method of installation. Cable bundles placed slightly apart from each other ignite faster and cause the flames to spread more rapidly than cable bundles placed closely together.

4) Influence of reinforcement. Addition of normal reinforcement does not noticeably improve the nonflammable properties of conventional cables. However, adding reinforcement causes a significant improvement on cables already constructed of anti-inflammatory materials. In this case, the rate of propagation is virtually nil.

HORIZONTAL PROPAGATION

The CESI test has chosen the most severe condition, where cables run in various directions, with horizontal and vertical sections. Nevertheless, there are cables which are generally installed horizontally.

Under this installation condition, conventional cables insulated with plastics or elastomers do not appreciably propagate flames. However, there are cases, such as in railway tunnels or mines for example, where the combustion gases are conveyed along the surface of the cables at a draft speed of about 50-100 m/l'. In these cases there may be long distances where it is impossible to provide flame traps, as is often possible in vertical runs where the cables pass from one level to the next.

Research was conducted to determine if conventional PVC cables could propagate flames under these conditions.

The installation in Fig. 3 represents a simple extension of the CESI test for horizontally placed cables. The steel tube is heated to red heat and the cables are then pushed horizontally through the tubing until one end reaches the ignition area. A normal fan maintains an air speed of 75 m/l'. The following test results were obtained on conventional cables, with the gas ignition burners in place for five minutes.

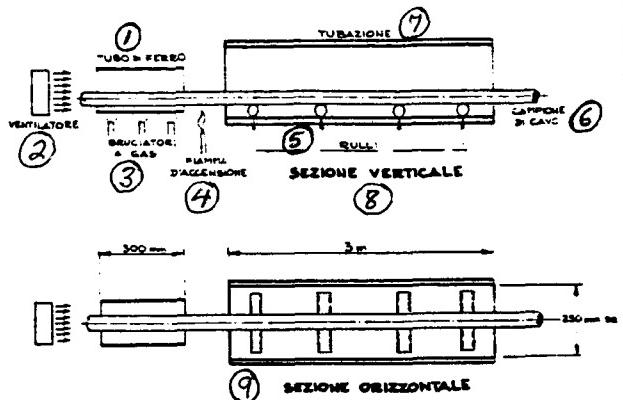


Fig. 3

Key: 1 - Iron tube; 2 - Fan; 3 - Gas burner; 4 - Ignition flame; 5 - Rollers; 6 - Sample cable; 7 - Tubing; 8 - Vertical station; 9 - Horizontal station.

Cable	Weight per Meter of Combustible Material kg/m	Propagation Distance m
Cable insulated with PVC with PVC sheath, iron wire reinforce- ment, PVC sheath, 19 conductors	1.2	3
Cable, c.s. 2 x 19 conductors	2.4	5
Cable insulated with PVC with PVC sheath, double reinforcement of iron wires, PVC sheath, 3 cond.	1.5	1
Cable c.s. 2 x 3 conductors	3.0	4

The results show that the flames propagate horizontally, which was already known from past fires. These results show that propagation increases with the quantity of combustible material, and that double reinforcement can significantly reduce propagation. /364

OTHER ASPECTS REGARDING CABLE FIRES

Opacity and toxicity of the fumes generated by cable fires is an important problem which, in certain installations, may be more damaging than fire propagation itself. For example, the presence of toxic and opaque gases in tunnels which are accessible to people and in subway systems, may cause a hazardous situation.

The opacity of fumes emanating from a nonflammable cable was determined in the laboratories of the Rubber and Plastic Research Association, with the following results:

Maximum fume density and percentage of light absorbed	Observations
Normal PVC compound used as a sheath	81
Sheath insulating com- pound of a nonflam- mable cable	97

On examining the results, a slight increase in fume density can be noted in the nonflammable cable. It must also be observed, however, that the quantity of fumes emitted during a fire is considerably lower for nonflammable cable than in traditional cables due specifically to their nonflammable properties.

The solution offered inevitably leads to the formation of toxic gas such as hydrochloric acid in constructions which, like Sintenax-flam, contain chloride substances. Research on generation of gas in the combustion of Sintenax-flam cables found that the behavior is identical to that which occurs when

cables insulated with traditional compounds burn. The principal components of the gases emitted are: hydrochloric acid (HCl), followed by carbon dioxide (CO_2), with a small quantity of carbon monoxide (CO)--no traces of phosgene were revealed. The high concentration of HCl suggests that it may be the most dangerous compound, even if small quantities of more highly toxic products such as CO are present.

The use of organic materials which do not contain halogens such as butyl, EPR, and reticulated polythene, may be interesting with regard to the toxic effects of the gases generated, but it involves an evaluation of the relative dangers of fume opacity, toxicity, and suffocation.

A question has been raised regarding whether the ignition temperature and the starting temperature of hydrochloric acid generation are different for the PCV additive compounds. Several research programs conducted on the subject show that the differences are sometimes positive and sometimes negative, but never by a great margin, so that we may conclude that there is no difference.

Another question raised was whether the aging of the operative cables has an effect on their nonflammable properties. Naturally, it was only possible to conduct accelerated tests which simulated aging and the results obtained from these tests did not show any loss of nonflammable properties. If we consider that plasticizer vapors are those that favor flame propagation, it is probable that the performance of nonflammable cables will improve with time.

Although nonflammable cables constitute a significant contribution, it must be remembered that at the moment there exists no economically acceptable solution for all the hazards inherent in a cable fire. It is interesting to note that research on the development of a "smokeless" cable will shortly

begin in the United States following a serious fire which broke out in a subway system.

ROUTINE TESTS AND QUALITY CONTROL

One criticism of the CESI test is that it is expensive, with regard to both equipment and execution. Nevertheless, only one test such as the CESI is required to enable us to predict the behavior of cable installations in case of fire. Just imagine, for example, that cable bundles which had regularly passed tests with 5 kg/m completely burned when they were tested with 10 kg/m, and that a 3-x-95-mm² cable, 3 kV, insulated with PVC, with PVC sheath, double reinforcement, underclad with PVC, propagated flames for 1.5 m when the reinforcement was protected with a thin layer of bitumen, but flames only spread 0.2 m when the bitumen was omitted.

ENEL requests Sintenax-flam type cables for their thermoelectric stations and requires a limited number of tests for every building lot, so that the cost of testing is less than 0.5% of the cost of the cable.

The problem of quality control during manufacture is just as important as that of routine testing. A notable number of Oxygen Index tests were conducted with sufficiently reproducible results, and the general opinion is that the CESI test must be used to define the structural characteristics of the cable, while the Oxygen Index is useful for controlling the types of materials used in manufacture.

(The Oxygen Index represents the minimum concentration of oxygen in an oxygen-nitrogen mixture necessary to maintain combustion in equilibrium with the conditions of the test being conducted).

Following is a report of several typical results obtained during production control testing:

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	<u>Oxygen Index %</u>
Conventional PVC insulation compounds	25
Conventional PVC sheathing compounds	23
Sintenax-flam insulation	36
Sintenax-flam sheathing	34
Fillers for multipolar Sintenax-flam cables	45 52

The procedure indicated above was adopted only after having established the the Oxygen Index test could not be extended to complete cables and that testing Oxygen Index values on individual cable components was not a satisfactory judgement criterion.

For this purpose a test was devised in which all the cable components were combined in the same proportions present within the cable. The Oxygen Index values found in these tests were compared with the results supplied in the CESI test without showing any corresponding values. For example:

3 x 2.5 mm ²	Insulated in EPR Hypalon fillers Anti-inflammatory PVC Sheath	Oxygen Index combined 28.6%	Result of CESI test: negative
2 x 300 mm ²	Insulated in EPR Anti-inflammatory PVC Sheath Armor PVC sheath	Oxygen Index combined 23%	Result of CESI test: positive

The reason that the two test results do not correspond can be explained but has no relevance here to the effects of deciding whether a combined Oxygen Index test is significant.

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